Enhancing Cooperative Behavior for P2P Reputation Systems by Group Selection (Theoretical Computer Science and Its Applications)

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Enhancing Cooperative Behavior for P2P Reputation Systems by Group Selection

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Abstract

Reputation systems are very useful in large online communities in which users may frequently have the opportunity to interact with users with whom they have no prior experience. Recently, how to enhance the cooperative behaviors in the reputation system that has became to one of the key open issues. Research in the evolutionary game theory shows that the group selection or multilevel selection can favor the cooperation in the finite populations. Further more, Nowak et al., in [1], [2] give a fundamental condition for the evolution of cooperation by group selection.Based on the above important result, we extend the group selection concept in evolutionary biology and propose a group-based mechanism to enhance cooperation for reputation systems in P2P network.

1. Introduction

1.1. Background

P2P networks define a class of systems and applications in which autonomous hosts (peers) pool their computing resources and collaborate to perform a special task. All peers have identical functionality and play the role in both servers and clients. Unfortunately, the lack of a centralized trusted entity capable of monitoring user behavior and enforcing rules complicates the design of mechanisms for detecting and preventing malicious behavior in autonomous environments. So, the importance of trust management became more and more crucial in open network. Trust and reputation techniques as one of the key issues in trust management have proven to be essential to enforcing cooperative behavior in peer-to-peer networks. Many solutions have been proposed in [3], [4], [5], [6], and each employing a different model of computing trust, disseminating and storing reputation data and responding to the non-cooperation in the network. However, the anonymousness and inherent virtually of the Internet hamper the implementation of the practical reputation system; the selfish peers always act to achieve their own best benefits by sharing no resources, or cheating others, and so on. For example, in Gunutella file-sharing system [7], over 70% of the content was provided by just 5% of the users. So, how to enhancing the cooperative behaviors has become the open problem in P2P reputation systems.

1.2. Motivation

Group selection refers to in evolutionary biology, and it was firstly proposed by Sewall Wright [8], then further resurrect by Wilon et al., whose works have been part of a broad revival of interest in group selection (or multilevel selection) as an explanation for evolutionary phenomena. The basic idea of group selection can be best illustrated by an example of the difference between group and individual selection, where selection on inner-group favors defectors, whereas selection on the inter-group favors cooperators. Contrasting to the individual selection theories which explain change in terms of the survival of individuals that are fitter than others and ignore the contexts of those individuals in terms of the strategies of others that an actor interacts with, group selection theories account for the co-evolution of both fitter individual strategies and groups of interacting strategies in groups, and it explains the emergence of cooperative groups [1], [2], [9], [10]. Recently, people also use group selection theory to explain the cooperative behavior in other applications filed, such as [11], [12]. Nowak et al., in [1], [2] give a fundamental condition for the evolution of cooperation by group selection, and it provides a mathematical method to analyze that under certain conditions nature selection can favor cooperative traits that benefit groups as a whole, but reduce individual fitness relative to the rest of their group.

Unfortunately, most of the existing research about the cooperation in reputation system ignore the significance of the social properties of peers and the importance of nature selection both in individual level and mareo-level. So, group selection mechanisms may offer a new way of explaining such a cooperation happened in reputation systems, also provider further insight into the way cooperation can and does develop and the factors affecting its emergence.

1.3. Related works

Considering the significance of the economic and social properties of peers in reputation systems, some research discuss and propose related mechanisms for the evolution of cooperation in multidisciplinary field. E.g, Lik Mui et al., in [13] stress the importance of social information when peers in the social network choose the targeted interactive object. In order to provide more cooperative agent communities, they propose a mathematical framework for modeling trust and reputation that is rooted in findings from the social sciences. Beverly Yang et al., in [14]propose an economic protocol to ensure that peers cooperate in the operation of P2P systems in the face of competition. Wang et al., in [15] propose new measurements to characterize the social properties of trust systems, and they use the Vickrey-Clarke-Grove-like reputation remuneration mechanism to simulate rational peers who truthfully offer feedback. Their result shows the emergence of certain social properties in trust networks.

Also, a few research inspired by the group selection for evolution of cooperation in evolutionary game theory. E.g, David Hales et al.in [16], [17] propose a simple selfish re-wiring protocol that can spontaneously self-organize networks into internally specialized groups, and related simulation shows their approach scalable, robust and emerging self-organizing phenomena. They make some strictly assumptions, something like: individual can discover others randomly from the network, compare its utility against others, and so on. However, these assumptions may not reflect the real situation in P2P reputation system.

1.4. Challenge Issues

Before to introduce the group-based mechanism to reputation systems in P2P network, some key challenges need to be resolved here. such as: research in biological and social communities shows that, as already mentioned, defector "wins" against cooperators within inner groups, while cooperator groups outperform defector groups. A tension therefore arises between the evolution of competitive behavior within groups and the evolution of cooperative groups. Do the same results apply to reputation systems in P2P network? If the results can apply, how can the groups evolve? such as: initialization of groups; members management, groups split, group elimination, and so on.

1.5. Our Contribution

The main contributions of this paper include:

- Extending the group selection in the evolutionary game theory, we propose a group based mechanism to enhance cooperation for P2P reputation system.
- Giving the basic theoretical analysis when applying the group selection theory to explain our proposed method, and doing some simulations about the proposed method.

The remainder of this paper is organized as following: Section 2 proposes a group based mechanism for enhancing cooperative behaviors in the reputation system. Section 3 gives the theoretical analysis of dynamics of P2P reputation systems.We will do some simulation to analyze our method in the Secction 4 Finally,we will concludes the paper.

2. Group Selection based Mechanism

2.1. Preliminary

From a sociological angle, individuals in the population have different relationship with each other. For example, individuals, genetic relatives or in same tribe (species), are prone to cooperate with each other. In order to describe the social property of individuals in P2P reputation system, we define and extend the concept of group as following:

Definition 1: *Group*, G, is the set of individuals with certain social relationship.

We assume that each group has a unique identity (*GroupID*) in the network, and each individual must belong to one group, and also with unique identity (*UserID*).

In social networks, the trust degree between people may be different due to the reason of emotion, preference, belief, and so on. In this paper, we simplify the process, and define the concept *friend factor* to reflect the trust degree of different individuals in the group:

Definition 2: *Friend factor*, f, is the trust degree between individuals in the group.

We assume that individual decide the friend factor according to the history of satisfaction transaction between individuals, and it can be computed it as following:

$$f = e^{\frac{(Num\_int - Num\_sat)\ln(0.1)}{Num\_int}}$$

Where the Num_int and Num_sat are threshold times of satisfaction interaction and actual satisfaction interaction times, respectively.

Fig.1 gives an example of the dynamics of friend factor between i and j. The increase of f is very slowly, while fast after several times interactions. This curve just reflects that people always keep the cautious attitude toward the unfamiliar ones, while like to reward the already known people. We can find that if individuals are more cooperative, then f will be bigger. By setting the value of Num_int, individuals can control the friend factor with others, also incent others to keep cooperation.

Definition 3: *Neighor* of source individual is the individual who have the direct interactive experience with it.

How can we imagine the behavior of individual in the P2P networks? That is a very tough problem to make

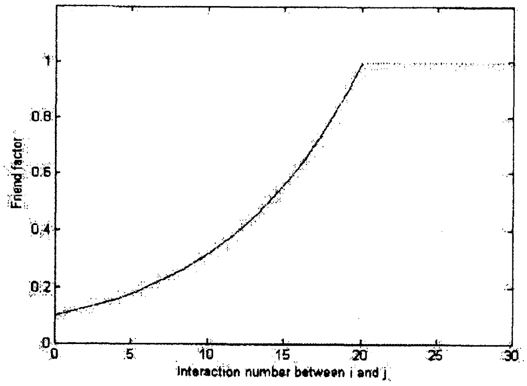

Figure 1. Friend Factor. The friend factor f climbs when the actual satisfaction interaction time increases, and it will keep at the constant 1 when the satisfaction times no less than the threshold satisfaction interaction. Here $Num\_int = 20$

that assumption. Unfortunately, it's the first obstacle before designing an ideal interaction protocol for P2P reputation systems. Some research makes assumption that individuals can act perfectly rationality, and with common knowledge. However, individuals in the open environment may be not familiar with each other. If there are no central and authorized individuals which can help them making trust decisions, individuals are hard to know the others strategies or possible outcomes, also some other random factors can affect the behavior of individuals. If we just simply assume that peers can do anything they want to, it may be too complex to beyond state-of-art analytical techniques [17].

Inspired the assumptions in [17], we conclude the behavioral assumption in this paper as follows.:

- Individual may change its current strategy when satisfaction score below the threshold value in the last interaction.
- Individual is bounded rationality and incomplete knowledge.Beside the benifits they get from transactions, individuals' strategies or behaviors also affected by other random factors (e.g., emotion, bias, etc). It means that they may not achieve the maximum benifits.
- The individuals in the different groups can't interact with each other.

Also, we make some assumptions about the scale of groups in this paper.

- The lower bound and upper bound number of individual in one group are t_1 and t_2 , respectively, and $t_1 > 2t_2$.
- The maximum number of groups in the network is m, and there is at least one group in the network.

Let N be the scale of the network, so, it satisfies:

$$t_2 \leq N \leq mt_1$$

Such assumptions make the network as realistic as possible, but also simple enough to be practically computable.

2.2. Group Formation

Group formation is a process that describes the dynamics of groups in the network. And it includes several processes, such as: *Group Initialization*, *Group Splitting* and *Group Elimination*. In the section, we will give the detailed information about these processes.

Group Initializtion. How can a new individual join this system? Fig.2 gives an example of the process of group initializtion.

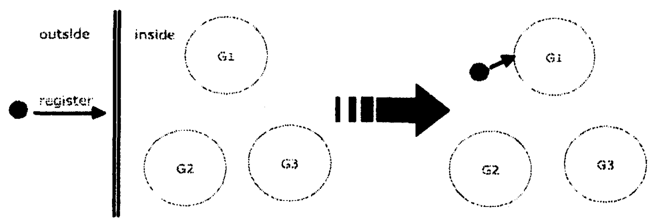

Figure 2. Initialization process. If a peer wants to join the system, it should register firstly. And the system will assign a unique identity to him, and then map the peer into a group (In the example, $G1$ chosen) based on certain principle.

The detailed process of *Group Initialization* is listed as following:

- *Registration*: the new individual register in the reputation system and the system will assign a unique identity to it.
- *Mapping to group*: The system will map the new entry into certain group in the network, and the probability of the group chosen is proportion to its size. Assuming that there are g groups $\{G_1, G_2, ..., G_g\}$, and let $\{n_1, n_2, , n_g\}$ be size values of the g groups, where n_i is the $i - th$ group scale. So, the probability of a individual a will map to $i - th$ group is:
$$Pr(a, G_i) = n_i / \sum_{j=1}^{g} n_j$$
- *Reputation Initialization.* Assigning the initial reputation to the new individual. This process is very important in the real reputation system. If the initial value is too small, the new individual will take long time to cumulate enough reputation to take part in cooperation with others. However, if the initial reputation is too high, the new individuals may be malicious or freeriders. The proposed method in [8] to solve this problem.

Group splitting. When the group size reach the upper bound t_2,it will be split into two sub-group with 1/2 chance, . Fig.3 gives an example that the *Group Splitting*:

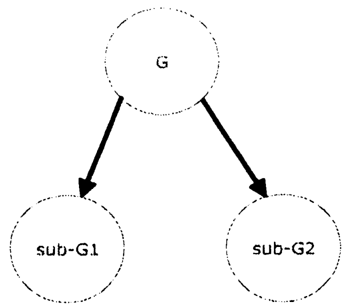

Figure 3. Group Splitting. G split into two sub-groups G_1 and G_2 when the scale of G exceed the t_2.

Note that the members in the splitting group will have equal chance to join the other two sub-groups .

Group elimination. There are two cases when the group elimination happens:

Case 1: the number of members in the group is less than the lower limit t_2.

Case 2: the number of group in the network is more than the upper limit m.

To case 1, we just remove the group ID in the system. But if the case 2 happens, the system will choose the lowest utility group to die.

When a group is chosen to delete from the system, how about the members in the group? We think that these individuals have choices to join other groups in the network. Note that they don't need to re-register in the system, but to keep its original ID, and reputation information. Here, we develop an algorithm to mapping these individuals into groups.

The detailed algorithm is list as follows:

1) Setting $counter\_time = 1$;
2) Mapping a into certain group, and the probability of a individual a joining certain group is proportion to the group's utility :$Pr(a, G_i) = f(U_{Gi})$,here f is arbitrary function, U_{Gi} is the utility of group G_i;
3) Assuming G be chosen in step 2, then G will check a's reputation. If $reputation(a) \geq avr\_reputaion(G)$. G accepts a as its member, then add a into G, end the algorithm;
4) Or else, then the G have 0.5 chance to refuse a's joining; if a is accepted, end the algorithm.
5) or else, If $counter\_time \leq 3$,then $counter\_time++$ and go to step 2;;
6) else end the algorihm.

As in the above algorithm, if the individual isn't accepted by certain groups within the three times, the system will automatically remove the individual. or if the invidual's repution is very low enough, it will be removed by system with nearly 1/8 probability.

2.3. Uncertain factors

Considering the uncertain factor in the open environment, we define some concept, originated from biology, to reflect the uncertain factors of peers' strategies.

Definition 4: *Migration* is the process that a individual move from one group to other group.

If individuals find that they can get more benefits from other groups, or just want to change their current environment, they may drop out their current groups, and then reenter to other groups. Let pr_mig be the probability of imitation of individual in each round.Fig.4 gives an example of indicial a migrate from the group G_1 to G_2.

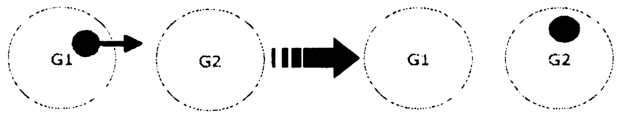

Figure 4. Migration process. Peer a in the group $G1$ is randomly chosen to migrate. Then,a will find its destination group based the certain principle. If $G2$ is chosen, then a will enter as a member of group $G2$.

Definition 5: *Mutation* is the process that a individual suddenly change its strategy to another random one.

In our mechanism, we allow a individual with certain probability to remove all its links between its neighbors, and then randomly links to one individual in the group to dicribe the individual mutation. Let pr_mut be the probablity of mutation of individual in each round.

Definition 6: *Merger* is the process that two groups merge into one bigger group.

Let pr_meg be the probability of group merger happens in the each round.

3. Theoretical Analysis

In the evolutionary game theory, the selection acts not only on the groups but also on individuals. If no other mechanisms, the defectors are initially favored by individual selection in the group, while the cooperative groups will win in the group selection.

In the P2P reputation system, individuals engage in some application task and generate some measure of utility U. U is a numeric value that everyone must calculate based on the particular application domain's specifics. For example, this might be the files downloaded, jobs processed, or an inverse measure of spy ware infections over some period. The higher the value of U, the better the node believes it's performing in its target domain.

Fig.5 describes the dynamics of the trust structure in P2P network. The individual plays trades with its neighbors which are individuals have the direct interaction with each

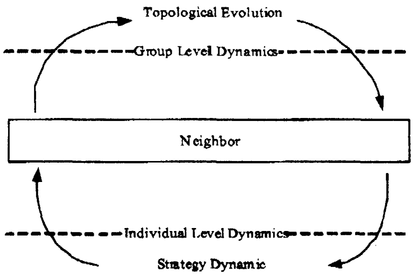

Figure 5. Adaptive of Trust Structure.

other. If the individual (not a pure altruists) always cannot benefit from the trade, then it will change strategy to adapt with the current environment. Thus, it will lead the strategy dynamic. However, the strategy dynamic of that individual may also affect the performance and strategies of its neighbors. The aggregation change and dynamics in the individual level can lead to the dynamics of the group level network which will lead the evolution of the network topology. Also, when facing to the new topology, an individual need to adaptive its personal strategies and behaviors to get some benefits from transaction between others. Thus, the feedback loop between an individual level and group level is formed.

To simplify the process, we assume that the interaction between individuals are Hawk-dove game, and there two strategies in the game: cooperate (C) , defect (D) . Due to the special relationship between the individual in the group, the payoff (or utility) matrix between individuals [18] is:

Table 1. Payoff Matrix.

-	C	D
C	$((b-c)(1+f),(b-c)(1+f))$	$(bf-c,b-fc)$
D	$(b-fc,br-c)$	$(0,0)$

Here c is cost of utility when joining the interaction, b is the benifit of utility from the interaction, and f is the friend factor between individuals.

4. Numerical Simulation

We will address by use of the NetLog 4.0.3 to analyze our proposed method. The basic parameters will be used in the network are listed in the Table 2.

Fig.6 shows the scene of Group Initialization. The new individual will be mapped into groups, and most groups with nearly same scale. Also, some groups suddenly become to big because of the group merger happening.

Fig. 7 shows that the selection will favor the cooperative groups. If the b/c is bigger enough,the cooperative groups will dominate the whole network quikly.

Fig. 8 and Fig.9 show the individual level selection, and we can see that cooperators and defectors will co-exist and all of them have chance to occupy the group when the b/c is smaller, while the b/c is big enough, cooperators will dominate over defector in the last.In fact, there may also happen defectors or cooperator disappeared if the network scale is small,which affected by random drift.

Fig.10 shows the average groups size in the network.As we can see that the average size will keep near a constant when time passing. In the beginning, we think that the cooperative groups may be more attractive and will become bigger and bigger. The reason that leads these phenomena not happened may be that the group will more risk to be affected by defectors when the scale of group is big.So, there is a tradeoff between the size and risk of the group.

Table 2. Simulation Parameters

Parameters	Description
d	initial degree of group
b/c	the ratio of benifits to cost
m	the upper bound of groups in the system
f	friend factor
t_1	frequency of cooperator
t_2	frequency of defector
pr_mig	probability of migitation
pr_mut	probability of mutation
pr_meg	probability of merger

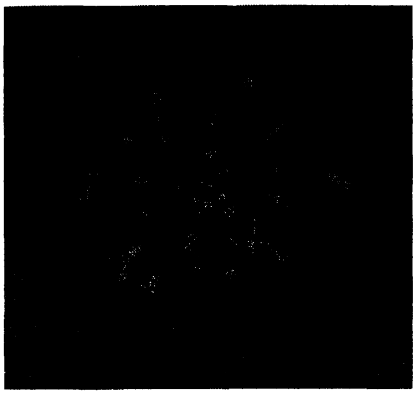

Figure 6. Group Initialization.The clusters in the network denote the group. The model parameters for this figure: $t_1 = 4$, $t_2 = 20$, $pr\_mut = 0$, $pr\_mig = 0$,$pr\_meg = 0.04$, $f = 1$ and $b/c = 1.3$

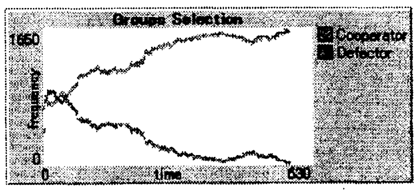

Figure 7. Group Selection.The model parameters for this figure: $d = 4$, $t_1 = 150$, $t_2 = 2000$, $pr\_mut = 0.03$, $pr\_mig = 0.07$,$pr\_meg = 0.04$ and $b/c = 1.60$

Figure 8. Individual Selection.The model parameters for this figure: $d = 4$,$t_1 = 150$, $t_2 = 2000$,$pr\_mut = 0.03$, $pr\_mig = 0.07$,$pr_meg = 0.04$and $b/c = 1.54$

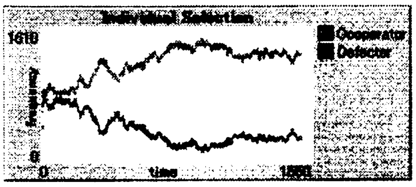

Figure 9. Individual Selection.The model parameters for this figure: $d = 4$,$t_1 = 150$,$t_2 = 3000$, $pr\_mut = 0.03$, $pr\_mig = 0.07$,$pr_meg = 0.04$and $b/c = 2.40$

5. Conclusions

In this paper, we extend the concept of group selection in evolutionary game theory, and provide a group based mechanism to enhance the cooperation in P2P reputation system. The related simulation results show that our method can enhance the cooperative behavior in the network.

Acknowledgments

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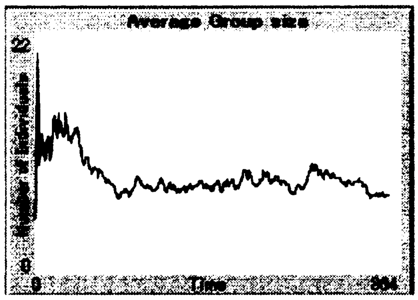

Figure 10. Average Group Size.The model parameters for this figure: $t_1 = 4$, $t_2 = 60$, $pr\_mut = 0.03$, $pr\_mig = 0.07$,$pr\_meg = 0.04$ and $b/c = 1.60$

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